

UTILITY CONTINUATION PATENT APPLICATION TRANSMITTAL

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jc540 U.S. PTO
09/224202

12/30/98

Attorney Docket No.: 3123-233-1

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Express Mail Label No.: EM552805705US

Title: "METHOD AND APPARATUS FOR DETECTING HEAD FLYING HEIGHT IN A DISK DRIVE"

Prior Group Art Unit: 2753

Prior Examiner: CULLEN, L.

Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

This is a Continuation application of pending prior application No. 08/764,340 filed December 12, 1996. The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied, is considered to be part of the disclosure of the accompanying application and is hereby incorporated by reference.

Enclosed for filing with the above-identified utility patent application, please find the following:

1. ☒ Copy of the entire Specification of the prior application as originally filed (49 pages of text and 9 drawing sheets comprising Figs. 1-9)
2. ☒ Copy of Oath/Declaration from the above-referenced pending prior application (37 CFR 1.63(d))
3. ☐ Assignment Papers (cover sheet & document(s))
4. ☐ 37 CFR 3.73(b) Statement (when there is an assignee)
5. ☐ Power of Attorney
6. ☐ Information Disclosure Statement (IDS/PTO-1449)
7. ☐ Copies of IDS Citations (Number of References:)
8. ☒ Preliminary Amendment
9. ☒ Return Postcard (MPEP 503) (should be specifically itemized)
10. ☐ Small Entity Statement(s)
11. ☐ Other:

FEE CALCULATION:

	(COL. 1) NO. FILED			(COL. 2*) NO. EXTRA		SMALL ENTITY			LARGE ENTITY	
						RATE	FEE		RATE	FEE
BASIC FEE:							\$380.00	OR		\$760.00
TOTAL CLAIMS:	20	-	20			X \$9 =		OR	X \$18 =	
INDEP. CLAIMS:	2	-	3			X \$39 =		OR	X \$78 =	
MULTIPLE DEPENDENT CLAIMS						+ \$130 =		OR	+ \$260 =	
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OTHER INFORMATION:

1. ☒ **FILING FEE IS NOT ENCLOSED AT THIS TIME.**
2. ☒ The Commissioner is hereby authorized to charge all required fees for extensions of time under §1.17 to Deposit Account No. 19-1970.
3. ☐ Foreign Priority benefits are claimed under 35 U.S.C. §119 of Patent Application Serial No. filed
4. ☒ The Power of Attorney appears in the original papers of the prior pending application.
5. ☒ The prior application is assigned to MAXTOR CORPORATION.
6. ☐ This application is being filed by less than all of the inventors named in the pending prior application. The Commissioner is requested to delete the name(s) of the following person(s) from the prior application who are not inventors being claimed in the application: .
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Respectfully Submitted,

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Date: Dec. 30, 1998

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re the Application of:

CARLSON ET AL.

Serial No.: To be assigned

Filed: Herewith

Atty. File No.: 3123-233-1

For: "METHOD AND APPARATUS FOR
DETECTING HEAD FLYING
HEIGHT IN A DISK DRIVE"

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

Please enter this preliminary amendment prior to both examining the present application and calculating the filing fee for the present application.

AMENDMENTS

Please enter the following amendments.

In the Abstract:

In line 15, please delete "Means are also provided" and insert --The system also provides-- therefor.

In the Claims:

Please cancel Claims 21-46 without prejudice to, or disclaimer of, the subject matter contained therein.

) Prior Group Art Unit: 2753

) Prior Examiner: CULLEN, L.

) PRELIMINARY AMENDMENT

"EXPRESS MAIL" MAILING NO.: EM552805705US
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TYPED OR PRINTED NAME: Lori R. Arellano

SIGNATURE: *Lori R. Arellano*

REMARKS

The present application, as originally filed, contained Claims 1-46. Through this preliminary amendment, Claims 21-46 have been canceled. Accordingly, Claims 1-20 are at issue in the present case.

Respectfully submitted,

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METHOD AND APPARATUS FOR DETECTING
HEAD FLYING HEIGHT IN A DISK DRIVE

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FIELD OF THE INVENTION

The invention relates in general to digital data storage devices and, more particularly, to digital data storage devices that utilize a head to transfer data from/to a moving medium.

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BACKGROUND OF THE INVENTION

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A disk drive is a digital data storage device that stores data in substantially concentric tracks on the surface of a disk. During the operation of a disk drive, the disk is rotated at a substantially constant rate while data is written to or read from its surface. The disk drive is generally coupled to a host computer that delivers access requests to the disk drive whenever the host desires to store or retrieve digital information. To perform an access request, the disk drive first positions a head above the track of the rotating disk specified in the access request. Once the head is properly positioned, the requested data transfer (i.e., either a read operation or a write operation) is allowed to take place. During a read operation, data from the predetermined track is sensed by the head, after which it is processed by a read channel and delivered to the host system. During a write operation, data is received from the host, processed into a suitable format, and then delivered to the head which transfers the data to the predetermined track.

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During operation of the disk drive, the head generally rides above the disk surface on a cushion of air (known as an air bearing) that is created by the movement of the disk under the head. The distance of the head from the disk while riding on the air bearing is referred to as the "flying height" of the head. To produce the "lift" required to hold up the head, head "sliders" are generally used that have the requisite aerodynamic qualities. In general, the performance of the disk drive will depend, to a great extent, on the maintenance of a proper head flying height. That is, performance will be degraded if the actual flying height of the head is considerably higher, for example, than a nominal flying height. This is particularly the case during write operations where an unexpected increase in flying height can result in written data that is unreadable.

A need therefore exists for a method and apparatus for determining whether the actual flying height of a head is within a desired range.

two analog read signal portions having different frequencies. In conceiving of the present invention, it was appreciated that the ability of a read head to read data patterns at higher frequencies diminishes at a faster rate than the
5 ability of the head to read lower frequency patterns as the head moves away from the disk. Because of this, read signal resolution changes in a predictable manner as the flying height of the head increases. In general, the invention determines a read signal resolution value, or a read signal
10 resolution related value, and then compares the value to a predetermined value to determine whether the flying height is in the proper range.

In one aspect of the present invention, a disk drive is provided that comprises a disk having a first data pattern
15 with a first frequency and a second data pattern with a second, higher frequency on a first track. The disk drive also includes means for reading the first and second data patterns, using a head at a first vertical distance from the disk, to create first and second analog signal portions,
20 respectively. In addition, the disk drive includes a determination unit for determining whether the first vertical distance of the head is within an acceptable range for performing a transfer of user data between the first track and an exterior environment using the first analog signal portion
25 and the second analog signal portion, wherein the determination unit does not require the movement of the head

to a substantially different vertical distance to make the determination.

5 The determination unit determines whether the first vertical distance is within the desired range based on read signal resolution. The read signal resolution can be calculated by taking the ratio of the magnitudes of the first and second analog signal portions. The determination unit can include a comparison unit for comparing the calculated read signal resolution to a threshold resolution value that
10 represents the maximum flying height that will result in an acceptable read or write performance. The resolution value can be stored in a memory along with other resolution values for different areas of the disk surface. For example, one stored threshold value can correspond to each zone on the
15 disk.

The first and second data patterns can be stored anywhere within the first track. In one embodiment, the patterns are stored in a servo data region of the first track. To decrease overhead on the disk, the patterns can be stored in standard
20 servo fields, such as the automatic gain control (AGC) field and/or the C/D servo burst fields. Alternatively, a dedicated servo field can be created for one or both of the patterns.

The disk drive can also include a unit for postponing the transfer of user data to the first track when it is determined
25 that the head is not within the proper vertical distance range. For example, the first data pattern and the second

data pattern can both be located in a servo sector immediately preceding a data area on the first track. The patterns can be read by the reading device and then the determination unit can determine whether the head is in the proper range. If the head is not in the proper range, the postponement unit can decide not to read or write data from/to the data area as the head proceeds to pass over the data area from the servo sector. The postponement unit can then perform a retry on the next revolution of the disk.

In one embodiment, the determination unit includes a transition detector for detecting indicia (such as, for example, peaks) in the second analog signal portion that are indicative of magnetic transitions stored on the surface of the disk. Because of the read signal resolution effect, when a relatively high frequency pattern is read by the head at an elevated flying height, some of the resulting indicia will not be detectable by the transition detector. Therefore, the number of indicia detected (and/or not detected) by the transition detector can be used as an indicator of flying height. The transition detector can include, for example, an analog peak detector, a PRML channel, a decision feedback equalizer, a finite delay tree search unit, or any other means for detecting indicia in a read signal.

In another aspect of the present invention, a disk drive is provided that includes a unit for determining whether the head is currently within an acceptable vertical distance from

the disk surface for performing a transfer of user data between the predetermined track and the exterior environment before a transfer of user data is allowed to occur, wherein the determination does not include means for changing a
5 current vertical distance between the head and the disk surface, and a transfer unit for performing the transfer of user data only when the head is determined to be within the acceptable vertical distance by the determination unit.

The determination unit operates in substantially real
10 time so that the required determination can be made before the transducer reaches the data area to/from which data is to be transferred. The determination unit can make the required determination based upon read signal resolution or any other method capable of real time operation. In addition, the
15 determination unit can include a comparison unit or peak detection unit as described above.

In yet another aspect of the present invention, a disk drive is provided comprising: a disk having a plurality of concentric tracks, the disk including a first pattern having
20 a first frequency and a second pattern having a second frequency, the second frequency being greater than the first frequency; a head for use in transferring data to/from the disk; means for reading the first pattern using the head to create a first analog waveform having a first magnitude value;
25 means for reading the second pattern using the head to create a second analog waveform having a second magnitude value; a

combining unit for combining the first magnitude value and the second magnitude value to create a read signal resolution related value; and a comparison unit for comparing the read signal resolution related value to a threshold value.

5 In one embodiment, the threshold value is based on a minimum read signal resolution that will produce an acceptable data transfer performance in the disk drive. The combining unit can include a means for finding a ratio between the first magnitude and the second magnitude. The comparison unit can
10 include a storage unit for storing a plurality of threshold values corresponding to different areas on the disk surface and a retrieval unit for retrieving one of the threshold values corresponding to a track currently being accessed.

 In still another aspect of the present invention, a disk
15 drive is provided comprising: a disk having a plurality of concentric tracks, the disk including a first track having a first data pattern with a first frequency; a head for use in transferring data to/from the disk; means for reading the first data pattern, using the head, to produce an analog read
20 signal having a predetermined number of peaks representative of data on the disk surface; a processing unit for processing the analog read signal to determine which of the peaks in the analog read signal meet a predetermined detection criterion, wherein less than all of the predetermined number of peaks
25 will meet the predetermined detection criterion when the head is not within the desired flying height range due to

relatively low read signal resolution at the first frequency,
the processing unit creating an output signal; and a
determination unit for determining whether the flying height
of the head is within the desired range based on the output
5 signal of the processing unit.

In one embodiment, the processing unit determines how
many of the peaks in the analog read signal meet the
predetermined detection criterion and then compares the
resulting peak count value to a threshold count value. As
10 described above, the comparison unit may include a data
storage unit for storing at least one, and preferably a
plurality, of threshold count values. In addition, the
determination unit can include a comparison unit for comparing
the peak count value to a table of predetermined count values
15 each having an associated flying height value to determine an
actual present flying height value. The first data pattern
can include, for example, a constant frequency data pattern or
a variable frequency data pattern, such as a chirp or random
pattern, that includes the first frequency. In addition, the
20 processing unit may include a transition detector as described
above.

In a further aspect of the present invention, a disk
drive is provided that includes a read channel including a
determination unit for determining whether a head is within an
25 acceptable vertical distance from a disk surface for
performing a transfer of user data between a track of the disk

and an exterior environment. In one embodiment, the channel, including the determination unit, is implemented on a single semiconductor chip. In another embodiment, the channel includes an optimization unit for optimizing the channel for performing the determination function by changing the value of
5 at least one of the channel parameters during a period when the determination unit is performing the determination function.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram illustrating a disk drive system that can utilize features of the present invention;

Fig. 2 is a sectional view of a disk and an associated head (having a head slider) illustrating the flying height of the head above the disk surface;

Fig. 3 is a diagram illustrating data storage patterns on a disk surface in accordance with one embodiment of the present invention;

Fig. 4 is a waveform illustrating portions of an analog read signal in accordance with one embodiment of the present invention;

Fig. 5 is a block diagram illustrating a flying height determination apparatus in accordance with one embodiment of the present invention;

Fig. 6 is a diagram illustrating data storage patterns on a disk surface in accordance with another embodiment of the present invention;

Fig. 7 is a diagram illustrating data storage patterns on a disk surface in accordance with yet another embodiment of the present invention;

Fig. 8 is a diagram illustrating a flying height determination apparatus in accordance with another embodiment of the present invention; and

DETAILED DESCRIPTION

The present invention relates to a system for detecting head flying height variations in a disk drive in real time. That is, the system allows head flying height to be checked on the fly while a corresponding read or write operation is being performed. In this way, read and/or write operations can be postponed whenever it is determined that the current flying height of the head is outside a normal flying height range. Although the system may be used in virtually any type of data recording system that uses a head to read/write information to a recording medium, the system is of particular value in systems that use low flying height head elements, where even small variations in flying height can degrade performance significantly. As used herein, the term low flying height head encompasses both contact heads and pseudo-contact heads.

Fig. 1 is a block diagram of a disk drive system 10 which can utilize features of the present invention. As illustrated, the disk drive system 10 is coupled to an external host unit 12 for performing disk storage and retrieval operations under the control of the host 12. The disk drive 10 includes: a disk 14, a spin motor (not shown) for rotating the disk 14, an actuator arm assembly 16, a head 18, a voice coil motor 20, a channel 22, an interface 24, a disk controller unit 26, and a servo control unit 28. The controller 26 is operative for controlling the operation and timing of the other elements in the disk drive system 10. The

interface 24 is operative for managing the flow of data to/from the host unit 12 and receiving commands from the host unit 12 for delivery to the controller 26. The channel 22 is operative for processing data flowing between the host 12 and the disk 14. For example, during a read operation, the channel 22 receives an analog read signal from the head 18 and converts this to a digital signal which is recognizable by the host 12. During a write operation, the channel processes a digital signal from the host 12 and converts it to a variable write current signal which is delivered to the head 18 for storage on the disk 14. The actuator arm 16 carries the head 18 at a distal end for positioning the head 18 above the disk 14. The voice coil motor 20 is operative for imparting motion to the actuator arm 16 during read and write operations to position the head 18 above a desired track on the surface of disk 14. The voice coil motor 20 is responsive to a servo control signal from servo control unit 28 that controllably positions the actuator arm 16 based on the location of the track requested by the host 12 in a recent access request.

In a preferred embodiment of the present invention, the head 18 is a low flying height head. The general trend in disk drives today is to design heads that ride closer to the disk surface than heads have in the past, i.e., low flying height heads. By riding closer to the disk surface, low flying height heads produce less spacing loss and are able to read/write data on the disk with greater definition, thereby

allowing more data to be stored in a given area on the disk surface. Low flying height heads, however, are generally more sensitive to variations in head flying height than are heads of the past. That is, in general, the performance of a low flying height head that normally flies at 2 microinches will be degraded to a much larger extent if the flying height of the head is temporarily increased by 2 microinches than would the performance of a head that normally flies at 5 microinches.

To exacerbate the problem, low flying height heads are more likely to experience variations in flying height than are higher flying height heads. For example, low flying height heads are more likely to pick up particles from the disk surface that increase the flying height of the head than are heads that fly at higher heights. That is, debris or lubrication material on the disk surface may attach to the underside of the head, resulting in a greater flying height due to increased lift from the debris/material or contact between the debris/material and the disk surface. The undesirable debris/material usually stays on the head for a short period of time causing a temporary flying height increase.

As described above, the invention is capable of detecting variations in head flying height in substantially real time. Fig. 2 is a sectional view illustrating what is meant by the term "flying height." As illustrated in the figure, during

operation, the head 18 (which, as illustrated, includes a slider) is raised above the surface of the disk 14 by a spacing 30 known as the flying height of the head 18. The spacing 30 is created by the interaction between air currents
5 above the disk 14, caused by rotation of the disk 14, and the aerodynamic qualities of the head slider. The slider is generally designed to keep the head within a certain predetermined flying height range during operation of the disk drive. When the head 18 is outside of this flying height
10 range, the performance of the disk drive 10 can be seriously compromised. For example, if the head 18 is too high above the surface of the disk 14 (i.e., the flying height is too large), the magnetic fields produced by the head 18 will not be strong enough at the disk surface 14 to properly store the
15 required magnetic transitions. This results in a recorded signal on the surface of the disk 14 that is weak and potentially unreadable by the head 18 during a subsequent read operation. Similarly, if the head 18 is too far above the surface of the disk 14, the head 18 may not be able to read
20 previously written data on the surface of the disk 14.

To detect flying height variations in real time, the present invention relies upon variations in read signal resolution with flying height. Read signal resolution is a performance measurement that is related to the disk drive's
25 ability to read information at different frequencies. In this regard, read signal resolution is generally calculated using

the ratio of the magnitudes of two analog read signal portions having different frequencies. For example, to measure read signal resolution, a burst having a first frequency can be read from the disk surface to create a first analog signal portion and then a burst having a second, higher frequency can be read from the disk surface to create a second analog signal portion. The read signal resolution can then be calculated based upon the ratio of the magnitude of the second signal portion to the magnitude of the first signal portion.

To maintain an accurate resolution measurement, both bursts have to be read at substantially the same head flying height. In conceiving the present invention, it was discovered that read signal resolution varies with head flying height in an inverse manner. That is, as the flying height of the head increases, the read signal resolution for the head decreases. This is because head performance at elevated frequency levels degrades more rapidly with increased flying height than does head performance at lower frequency levels.

Fig. 3 is a diagram illustrating the informational content of a portion of a disk surface in accordance with one embodiment of the present invention. As illustrated, the surface portion includes a plurality of data regions 32 that are periodically interrupted by servo positioning information portions 34. It should be appreciated that although the present embodiment of the invention is implemented in a system using an embedded servo scheme, the invention can also be

implemented in systems using dedicated or hybrid servo schemes. The plurality of data regions 32 are arranged in concentric tracks on the disk surface. Each servo positioning information portion 34 includes, among other things, at least one automatic gain control (AGC) field 40 centered on a corresponding track and a plurality of servo positioning bursts (i.e., an A burst 42, a B burst 44, a C burst 46, and a D burst 48) for use by servo unit 28 in positioning the head 18 above the track. It should be appreciated that other servo information may also be present in each servo positioning portion 34 of Fig. 3 in accordance with the present invention. However, for purposes of convenience and clarity, the illustrated servo positioning portion 34 has been limited to the elements shown.

The AGC field 40 is used by the disk drive 10 to, among other things, set the gain of the channel 22 during read operations. That is, the head 18 reads the AGC field 40 and uses the magnitude of the resulting analog read signal to determine the optimal gain of the channel 22. As described above, the servo bursts 42-48 are used by the disk drive system 10 for, among other things, positioning the head 18 above the disk 14. The A/B bursts 42, 44 are used primarily during track following operations (i.e., maintaining the head 18 over the corresponding track) and the C/D bursts 46, 48 are used primarily during seek and settling operations (i.e., moving the head 18 from one track to another). In general,

the A, B, C, and D bursts 42-48 are each comprised of a plurality of successive, equally spaced magnetic transitions on the surface of the disk. As these transitions are read by the head, a substantially periodic analog read signal is created. The frequency of the resulting read signal is related to how closely the transitions are packed in the corresponding burst, i.e., how many transitions occur in a given angular portion of the disk. As used herein, the "frequency" of a burst refers to the frequency of the analog read signal that results from the sensing of the burst by the head 18.

In past systems, the frequency of the AGC field 40 was the same as the frequency of all of the other bursts 42-48. In accordance with one embodiment of the present invention, the C burst 46 and the D burst 48 are recorded on the surface of the disk 14 at a frequency that is higher than the frequency of the AGC field 40 and both the A burst 42 and the B burst 44. Therefore, when the head 18 is centered on one of the tracks, it is possible to find a magnitude of the analog read signal for both the AGC burst 40 and either the C burst 46 or the D burst 48, depending upon which one is centered for the particular track. Fig. 4 illustrates portions of an analog read signal resulting from the reading of an AGC field 40 and a C or D burst 46, 48. As illustrated, the C/D portion of the signal is at a higher frequency than the AGC portion of the signal. Consequently, the magnitude of the AGC portion is

greater than the magnitude of the C/D portion. The ratio between the frequency of the AGC field 40 and the frequency of the C/D burst 46, 48 is chosen to provide a measurable change in resolution for flying height changes of interest at all disk locations. In addition, the frequency of the C/D burst can be different at different track locations (i.e, zoned) to optimize the measurable resolution change.

Fig. 5 is a block diagram illustrating an apparatus 50, in accordance with the present invention, for determining whether the head 18 is within a proper flying height range using the analog signal portions of Fig. 4. In one embodiment of the present invention, the apparatus 50 is located within the channel 22 of the system 10. For example, the apparatus 50 can be implemented on the same semiconductor chip as the channel 22. Alternatively, the bulk of the operations performed by apparatus 50 can be implemented in firmware in the controller 26.

The apparatus 50 includes: AGC circuitry 51, a magnitude detector 52, a register 54, a resolution measurement unit (RMU) 56, a comparator 58, and a random access memory (RAM) 60. As illustrated in Fig. 5, the apparatus 50 receives the analog read signal from the head 18 at an input 62. The AGC circuitry 51 receives the analog read signal from input 62 and normalizes the magnitude of other portions of the read signal to the magnitude of the AGC portion of the signal. The AGC circuitry 51 then delivers the processed read signal to the

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magnitude detector 52 and to other circuitry in the channel. Under the control of the controller 26, the magnitude detector 52 first measures the magnitude of the AGC portion of the analog signal. The magnitude of the AGC portion is then delivered to the register 54, under the control of the controller 26, where it is stored for later use. The magnitude detector 52 then measures the magnitude of the C/D portion of the analog read signal. The magnitude of the C/D portion and the stored magnitude of the AGC portion are next delivered to the RMU 56 for calculation of the read signal resolution. The resulting read signal resolution value is then compared, in comparator 58, to a threshold resolution value, stored in RAM 60, corresponding to the portion of the disk 14 being accessed. The threshold values stored in the RAM 60 represent the read signal resolutions at the maximum head flying heights that will result in an acceptable performance of the disk drive system 10. Each value stored in the RAM 60 corresponds to a different area on the disk surface (such as, for example, a different zone, track, or sector.) The output of the comparator 58, therefore, is indicative of whether the present flying height of the head 18 is adequate for the performance of a read and/or write operation.

This flying height indication is delivered to the controller 26 which makes a decision as to whether the corresponding read/write operation should be postponed. If a decision is made to postpone the operation, the controller 26

will ignore the subsequent data area 36 (that is, the data area 36 following the present servo portion 34) and attempt to "retry" the read/write operation when the disk rotates to a point where the servo portion 34 and the data area 36 once again pass under the head 18. If, after repeated passes, the head 18 does not fall within the prescribed flying height range, the controller 26 will determine that an error condition exists and can indicate such to the host. Alternatively, the controller 26 can initiate remedial action designed to overcome a presumed cause of the defective flying height. For example, the controller 26 can initiate a routine designed to remove any foreign matter from the air bearing surface of the head 18. Also, the controller 26 can perform a write operation ignoring detection of the high flying condition and then perform a read operation on the same data to determine whether it was properly written. Furthermore, for write operations, the data can be moved to a new location and the defective location can be marked bad.

In one embodiment of the present invention, the need for additional circuitry can be reduced or eliminated through efficient use of the AGC circuitry 51 of the channel 22. As described above, the function of the AGC circuitry 51 is, in general, to normalize the magnitude of other portions of the read signal to the magnitude of the AGC portion of the signal. Therefore, the AGC circuitry 51 normalizes the C/D portion of the signal to the magnitude of the AGC portion, by

amplification. The magnitude of the normalized C/D burst can then be measured and compared directly to a predetermined threshold value in RAM for that track (or portion of the disk). This reduces circuit complexity and cost since it is not necessary to measure the amplitude of the AGC portion 40. Therefore, by efficient use of the AGC circuitry 51, the present embodiment can be implemented with little or no additional circuitry and some additional firmware.

Because the present approach only requires a change in the frequency of the C and D bursts, on-track servo following is not affected. That is, the A and B bursts are used in the same manner that they are used in prior art servo systems. The C and D bursts, which are normally used during seeking and settling functions, are also used in substantially the same manner that they were used in the prior art. That is, even though an elevated frequency is being used for the C and D bursts, the relative magnitudes of the corresponding read signal portions should be substantially the same.

In another embodiment of the present invention, as illustrated in Fig. 6, a dedicated D burst 48 is used that is continuous across the disk surface. That is, the D burst extends across all of the tracks and is exclusively used to determine the read signal resolution of the head 18. This technique allows a head flying height determination to be made while the head 18 is either on or off the track. As in the prior embodiment, the present embodiment does not affect track

following operations, but could affect seeking and settling operations due to the fact that only a single quad (i.e., C or D) burst is available.

Fig. 7 illustrates a servo pattern in accordance with yet another embodiment of the present invention. As illustrated, the servo pattern includes an E burst 62 extending across the surface of the disk. Only the E burst 62 will have a frequency that is greater than the other bursts. That is, the AGC burst 40 and the A, B, C, and D bursts 42-48 will all have the same frequency, while the E burst 62 will have an elevated frequency. Read signal resolution will be measured in substantially the same manner as described previously, except that the higher frequency signal portion will result from the E burst 62. Because this embodiment does not change any of the A to D bursts 42-48, track following, seeking, and settling operations are substantially unaffected. However, the addition of servo burst E 62 adds overhead to the system and requires a change in the current ASIC chip controlling the servo field strobes.

Fig. 8 illustrates an apparatus 70 in accordance with another embodiment of the present invention. The apparatus 70 is capable of detecting whether the head 18 is within an acceptable flying height range based upon the number of peaks (or other indicia) in an analog read signal that are detected (or not detected) by a transition detector. As the flying height of the head increases, the read signal resolution

decreases causing a decrease in read signal amplitude at higher frequencies. Therefore, when a pattern having an elevated frequency is read by the head at a relatively high flying height, the reduced read signal resolution can result in an analog read signal that has a number of peaks (or other indicia) that are undetectable by a transition detector. The number of peaks that are detectable, therefore, can be used as an indication of the flying height of the head 18. The apparatus 70 counts the number of detected peaks and uses the count to determine whether the head 18 is at a proper flying height. The apparatus 70 can be implemented in the channel 22, in the controller 26, or in another location in the disk drive 10.

The apparatus 70 includes: a transition detector 72, a counter 74, and a random access memory (RAM) 76. During operation, the head 18 reads a data pattern from the surface of disk 14 and delivers a resulting analog read signal to the transition detector 72. The transition detector 72 is used to detect events in the analog read signal, such as peaks, indicative of magnetic transitions stored on the disk 14. The transition detector 72 creates an output signal indicative of the location of peaks (or other indicia of magnetic transitions on the disk) in the analog read signal. In general, most transition detectors only indicate the detection of a transition if, among other things, the magnitude of the analog read signal exceeds a predetermined threshold value at

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elevated frequency, such as those discussed earlier with respect to servo bursts C, D, and E. In another approach, a random pattern is used that results in a peak count that is directly proportional to the flying height. In general, the
5 random pattern is determined by empirical methods and is longer than the constant frequency pattern discussed above.

In yet another approach, a data pattern having a linearly increasing frequency (i.e., a chirp pattern) is used. Fig. 9 illustrates an analog read signal resulting from the reading
10 of such a chirp pattern. As seen in the figure, the magnitude of the analog read signal decreases as the frequency of the signal increases. This is due to the resolution effect. The magnitude will eventually decrease to a point where peaks can no longer be detected by transition detector 72. The
15 controller 26 determines the point in the pattern (and, therefore, the cutoff frequency) at which peaks in the analog read signal cease to be detected. The controller 26 then determines whether the present flying height of the head 18 is proper based upon the detected cutoff frequency.
20 Alternatively, the controller 26 can determine whether the present flying height is proper based on a peak count as described above. The length of the chirp pattern in any particular implementation will depend on the range of expected flying heights as well as the ability to correct for head
25 radius using read channel detection level adjustments. In this regard, the length of the chirp pattern generally falls

approach, the RAM 76 can include parameters from which an appropriate flying height equation (as a function of measured count value or cutoff frequency value) can be synthesized for each area of the disk surface.

5 As described above, the transition detector 72 is used to detect events in the analog read signal, such as peaks, indicative of magnetic transitions stored on the disk 14. In this regard, the transition detector 72 may include virtually any type of transition detection device commonly used in
10 digital data storage systems such as, for example, analog peak detector circuitry, partial response/maximum likelihood (PRML) circuitry, decision feedback equalizer (DFE) circuitry, and finite delay tree search (FDTS) circuitry. The transition detector 72 can be the same detector used in the channel 22 to
15 create the digital output signal which is transferred to the host 12 or it can be a dedicated unit which is specifically implemented to perform the flying height determination function. The counter 74 may include any type of digital counting unit that can be controlled by the controller 26 or
20 other controlling means. In one embodiment of the invention, the counter 74 and the RAM 76 are implemented within the controller 26.

In general, the channel 22 in a disk drive system will have a number of variable parameter inputs which affect the
25 performance of the channel 22. The values applied to these variable parameter inputs will affect, for example, the

ability of the system to detect flying height variations. In one embodiment of the present invention, the values applied to the variable parameter inputs of channel 22 are changed whenever a flying height determination is being performed.

5 That is, channel parameter values are applied to the channel 22 which optimize the channel for the performance of the flying height determination and are then changed back to normal channel parameter values, optimized for performing read operations, after the flying height determination has been
10 made. For example, it may be determined empirically that the optimal transition detector threshold value for flying height determination is somewhat greater than the threshold value which is optimal for general transition detection. While the head 18 is reading the relevant pattern on the disk 14 during
15 the flying height determination, the controller 26 can cause the threshold value of the transition detector to be changed to the optimal flying height value. In one embodiment, a random access memory is provided for storing optimal flying height channel configuration values for all areas of the disk
20 surface.

Although the present invention has been described in conjunction with its preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the
25 invention as those skilled in the art readily understand. For example, the patterns used to determine or sense read signal

resolution do not have to be located within the servo portion
of the disk surface but, alternatively, can be located in a
data region on the disk. This can be useful, for example, in
a system using dedicated servo techniques. In addition, the
5 AGC field 40 can be modified to include both the high and the
low frequency patterns used to determine the read signal
resolution. For example, an alternating pattern of high and
low frequencies can be implemented in the AGC field 40 so that
the channel can set its gain using the low frequency portion
10 and measure read signal resolution using the high frequency
portion. Such modifications and variations are considered to
be within the purview and scope of the invention and the
appended claims.

surface of said head is at substantially the same unknown vertical distance above said disk surface; and

means for determining whether said unknown vertical distance of said head is within an acceptable range for performing a transfer of user data between said first track and said exterior environment using said first analog signal and said second analog signal, wherein said means for determining does not require movement of said head to a substantially different vertical distance to make said determination.

2. The disk drive, as claimed in Claim 1, wherein:

said means for determining determines whether said unknown vertical distance is within said range based on read signal resolution.

3. The disk drive, as claimed in Claim 2, wherein:

said means for determining includes means for calculating read signal resolution based on a ratio between a magnitude of said first analog signal and a magnitude of said second analog signal.

4. The disk drive, as claimed in Claim 1, wherein:

said means for determining includes means for comparing a calculated read signal resolution value to a threshold resolution value.

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5. The disk drive, as claimed in Claim 1, wherein:
said means for determining includes means for storing a plurality of threshold resolution values, wherein each stored value corresponds to a different region on said disk surface.

6. The disk drive, as claimed in Claim 1, wherein:
at least one of said first data pattern and said second data pattern is located in a servo data portion of said first track.

7. The disk drive, as claimed in Claim 6, wherein:
at least one of said first data pattern and said second data pattern is located in a standard servo field in said servo data portion.

8. The disk drive, as claimed in Claim 7, wherein:
said standard servo field includes at least one of the following: an automatic gain control (AGC) field; a C burst field, and a D burst field.

9. The disk drive, as claimed in Claim 7, wherein:
said first data pattern is located in an AGC field and said second data pattern is located in one of a C burst field and a D burst field.

10. The disk drive, as claimed in Claim 7, wherein:

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said first data pattern and said second data pattern are both located in the same servo field.

11. The disk drive, as claimed in Claim 1, wherein:

said first data pattern and said second data pattern are both located in a single servo sector on said first track, said single servo sector being associated with a data area on said first track that is adjacent to said single servo sector so that said head first traverses said single servo sector and then immediately traverses said associated data area on any particular revolution of said disk; and

said disk drive further comprises means for postponing a transfer of data from/to said associated data area if said means for determining determines that said unknown vertical distance is not within said acceptable range.

12. The disk drive, as claimed in Claim 1, wherein:

said second analog signal includes indicia corresponding to transitions in said second data pattern; and

said means for determining includes means for detecting said indicia in said second analog signal.

13. The disk drive, as claimed in Claim 12, wherein:

said means for detecting indicia includes at least one of the following: an analog peak detector, a PRML channel, a

decision feedback equalizer, and a finite delay tree search
5 unit.

14. The disk drive, as claimed in Claim 12, wherein:
said indicia includes a predetermined number of peaks in
said second analog signal; and
said means for detecting includes peak detection means.

15. The disk drive, as claimed in Claim 14, wherein:
said peak detection means may detect less than said
predetermined number of peaks in said second analog signal
portion due to read signal resolution effects that result in
5 reduced peak amplitudes at higher frequencies.

16. The disk drive, as claimed in Claim 15, wherein:
said means for determining includes means for determining
the magnitude of said unknown vertical distance based upon the
number of peaks detected and not detected by said peak
5 detection means.

17. The disk drive, as claimed in Claim 12, wherein:
said second data pattern is substantially centered on
said predetermined track and includes one of the following:
a constant frequency pattern, a random pattern, and a linearly
5 increasing frequency pattern.

18. The disk drive, as claimed in Claim 1, wherein:

said means for determining includes a read channel located between said head and said exterior environment for processing said first and said second analog signal portions
5 during the determination process and means for configuring said read channel, during the determination process, to enhance the ability of said means for determining to determine whether said head is within said acceptable distance from said disk surface.

19. A disk drive, comprising:

a disk having a plurality of concentric tracks upon a surface of the disk, wherein each track includes at least one servo sector for storing head positioning data and at least
5 one data sector for storing user data;

a motor for rotating said disk at a substantially constant angular velocity;

a head for use in transferring data between a predetermined track of said disk and an exterior environment,
10 wherein the ability of said head to transfer data between said predetermined track and said exterior environment is dependent upon the vertical distance between said head and said disk surface during said data transfer, wherein said vertical distance is measured along a normal line to said disk surface;

15 an actuator assembly for radially positioning said head with respect to said disk in response to a control signal;

means for determining, while said head is located above said predetermined track, whether said head is currently within an acceptable vertical distance range from said disk
20 surface for performing a transfer of user data between said predetermined track and said exterior environment, wherein said means for determining makes said determination before said transfer of user data is allowed to occur; and

means for postponing said transfer of user data when said
25 head is determined to be outside of said acceptable vertical distance range by said means for determining.

20. The disk drive, as claimed in Claim 19, wherein:

said means for determining operates substantially in real time so that, on a single revolution of said disk, said determination is made before said head reaches a data sector
5 on said predetermined track with which said transfer of user data is to take place.

21. The disk drive, as claimed in Claim 19, wherein:

said predetermined track includes a first data pattern at a first frequency and a second data pattern at a second frequency that is greater than said first frequency;

5 said disk drive further includes means for creating a first analog signal and a second analog signal by sensing said first data pattern and said second data pattern, respectively, using said head; and

said means for determining includes means for calculating
10 a read signal resolution value using a magnitude of said first analog signal and a magnitude of said second analog signal.

22. The disk drive, as claimed in Claim 21, wherein:

said means for determining includes means for comparing said calculated read signal resolution value to a predetermined limit value.

23. The disk drive, as claimed in Claim 19, wherein said means for determining includes:

means for reading a data pattern having a predetermined length from said predetermined track to produce an analog read
5 signal;

means for detecting peaks in said analog read signal; and
means for counting the number of peaks detected by said
means for detecting to produce a peak count value.

24. The disk drive, as claimed in Claim 23, wherein:
said means for determining includes means for comparing
said peak count value to a predetermined value.

25. The disk drive, as claimed in Claim 19, wherein:
said means for determining does not change the current
vertical distance between said head and said disk surface to
perform said determination.

26. A disk drive capable of determining whether a present flying height of a head above a surface of a disk in said disk drive is within an acceptable range for transferring user data between said disk and an exterior environment,
5 comprising:

a disk having a plurality of concentric tracks, said disk including a first pattern having a first frequency and a second pattern having a second frequency, wherein said second frequency is greater than said first frequency;

10 a head for use in transferring data to/from said disk;
means for reading said first pattern using said head to create a first analog waveform having a first magnitude value;
means for reading said second pattern using said head to create a second analog waveform having a second magnitude
15 value;
means for combining said first magnitude value and said second magnitude value to create a read signal resolution related value; and
means for comparing said read signal resolution related
20 value to a threshold value.

27. The disk drive, as claimed in Claim 26, wherein:

said threshold value is based on a minimum read signal resolution that will produce an acceptable performance in said disk drive while transferring user data between said disk and
5 said exterior environment.

28. The disk drive, as claimed in Claim 26, wherein:

said means for comparing includes means for storing a plurality of threshold values, wherein each threshold value corresponds to a predetermined portion of said disk surface.

29. The disk drive, as claimed in Claim 28, wherein:

said means for comparing includes means for retrieving a threshold value corresponding to a track currently being accessed from said means for storing.

30. A disk drive capable of determining whether a present flying height of a head above a disk surface is within a desired range, comprising:

a disk having a plurality of concentric tracks, said disk
5 including a first track having a first data pattern with a first frequency;

a head for use in transferring data to/from said disk;

means for reading said first data pattern, using said head, to produce an analog read signal having a predetermined
10 number of peaks representative of data on said disk surface;

means for processing said analog read signal to determine which of said peaks in said analog read signal meet a predetermined detection criterion, wherein less than all of said predetermined number of peaks will meet said
15 predetermined detection criterion when said head is not within said desired flying height range due to relatively low read signal resolution at said first frequency, said means for processing creating an output signal; and

means for determining whether the flying height of said
20 head is within said desired range based on said output signal of said means for processing.

31. The disk drive, as claimed in Claim 30, wherein:

said means for processing determines how many of said peaks in said analog read signal meet said predetermined

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detection criterion, said means for processing producing a
5 peak count value.

32. The disk drive, as claimed in Claim 31, wherein:
said means for determining includes means for comparing
said peak count value to a threshold count value, wherein said
threshold count value represents a minimum count value that
5 will result in an acceptable read/write performance of said
disk drive.

33. The disk drive, as claimed in Claim 32, wherein:
said means for comparing includes data storage means for
storing at least one threshold count value.

34. The disk drive, as claimed in Claim 33, wherein:
said data storage means stores a plurality of threshold
count values, wherein each stored value corresponds to a
predetermined region on the disk surface.

35. The disk drive, as claimed in Claim 31, wherein:
said means for determining includes means for comparing
said peak count value to a table of predetermined count values
each having a corresponding flying height value, to determine
5 an actual present flying height value.

36. The disk drive, as claimed in Claim 30, wherein:

said first data pattern includes a variable frequency data pattern.

37. The disk drive, as claimed in Claim 36, wherein:

said variable frequency data pattern includes a data pattern having a linearly increasing frequency.

38. The disk drive, as claimed in Claim 37, wherein:

said means for processing includes means for determining a cutoff frequency within said linearly increasing frequency data pattern above which peaks in a corresponding analog read
5 signal do not meet said predetermined detection criterion.

39. The disk drive, as claimed in Claim 38, wherein:

said means for determining includes means for comparing said cutoff frequency to a predetermined threshold cutoff frequency.

40. The disk drive, as claimed in Claim 36, wherein:

said variable frequency data pattern includes a random pattern that, when read by said head, results in a peak count that is substantially proportional to the flying height of
5 said head.

41. The disk drive, as claimed in Claim 40, wherein:

said random pattern is developed by empirical means.

42. The disk drive, as claimed in Claim 30, wherein:
said means for processing includes a transition detector.

43. The disk drive, as claimed in Claim 42, wherein:
said transition detector includes one of the following:
an analog peak detector, a PRML channel, a decision feedback
equalizer, and a finite delay tree search unit.

44. A disk drive, comprising:

a disk having a plurality of concentric tracks upon a surface of said disk for storing data;

a motor for rotating said disk at a substantially
5 constant angular velocity;

a head for use in reading/writing data from/to a predetermined track of said disk when said head is positioned above said predetermined track, wherein the ability of said head to transfer data from/to said predetermined track is
10 dependent upon a vertical distance between an air bearing surface of said head and said disk surface during said data transfer, wherein said vertical distance is measured along a normal line to said disk surface;

positioning means for radially positioning said head with
15 respect to said disk, in response to a control signal; and

a read channel, located between said head and an exterior environment, for processing data being read from said predetermined track by said head, said read channel including means for determining whether said head is within an
20 acceptable distance from said disk surface for performing a transfer of user data between said predetermined track and said exterior environment.

45. The disk drive, as claimed in Claim 44, wherein:

said channel, including said means for determining, is implemented on a single semiconductor chip.

46. The disk drive, as claimed in Claim 44, wherein:

said channel includes a plurality of variable channel parameters and means for changing the value of at least one of said variable channel parameters when said means for
5 determining is performing the determination function, wherein the new value of said at least one variable channel parameter is chosen to enhance said determination function.

ABSTRACT

The present invention relates to a system for determining whether the flying height of a read/write head above a disk in a disk drive is within an acceptable range, in substantially
5 real time. The system relies on variations in read signal resolution with flying height to make the determination. In one embodiment, read signal resolution is measured and compared to a predetermined threshold value to determine whether the present flying height is in the desired range. In
10 another embodiment, the number of peaks in a read signal that are detected (and/or not detected) by a detector is used to determine whether the head is in the proper flying height range. Because of read signal resolution effects, the number of detected peaks will decrease as the flying height of the
15 head is increased. Means are also provided for postponing a transfer of data to/from the disk when it is determined that the head is not within the acceptable range.

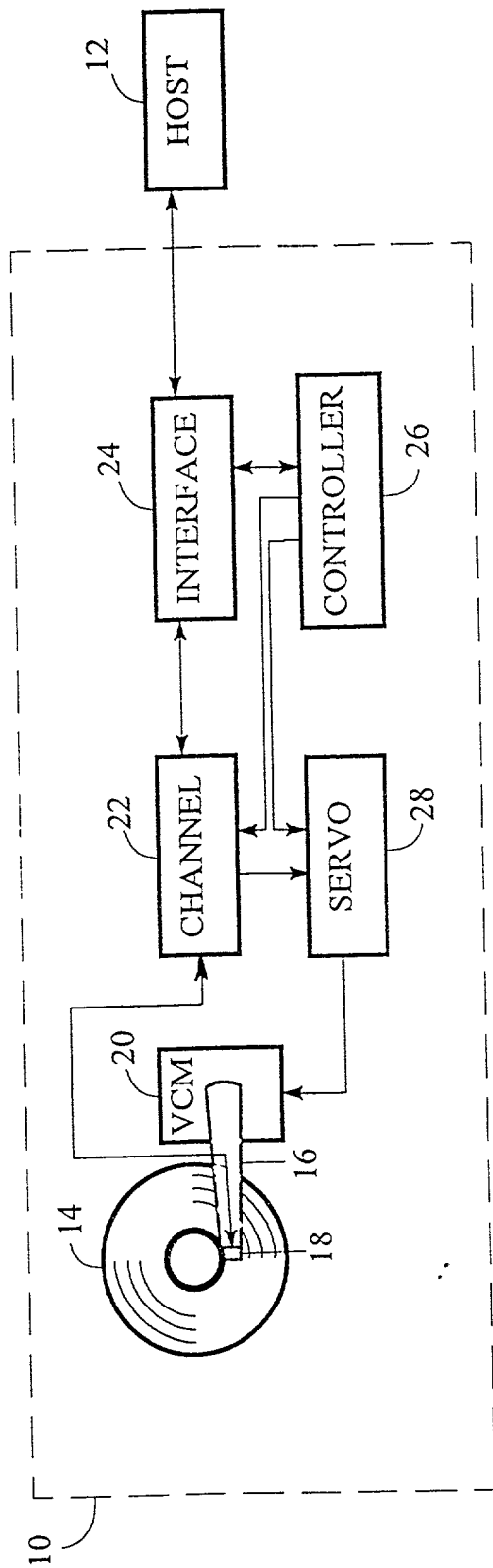


FIG. 1 (PRIOR ART)

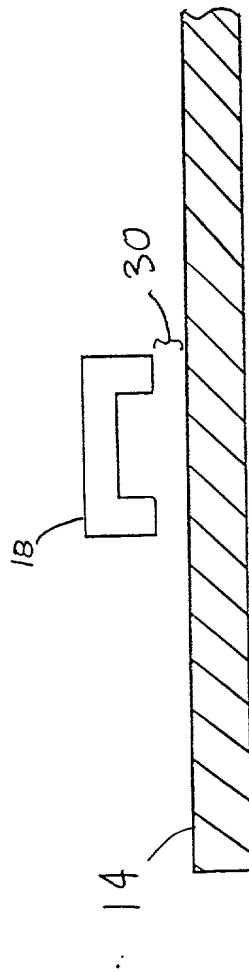


FIG. 2

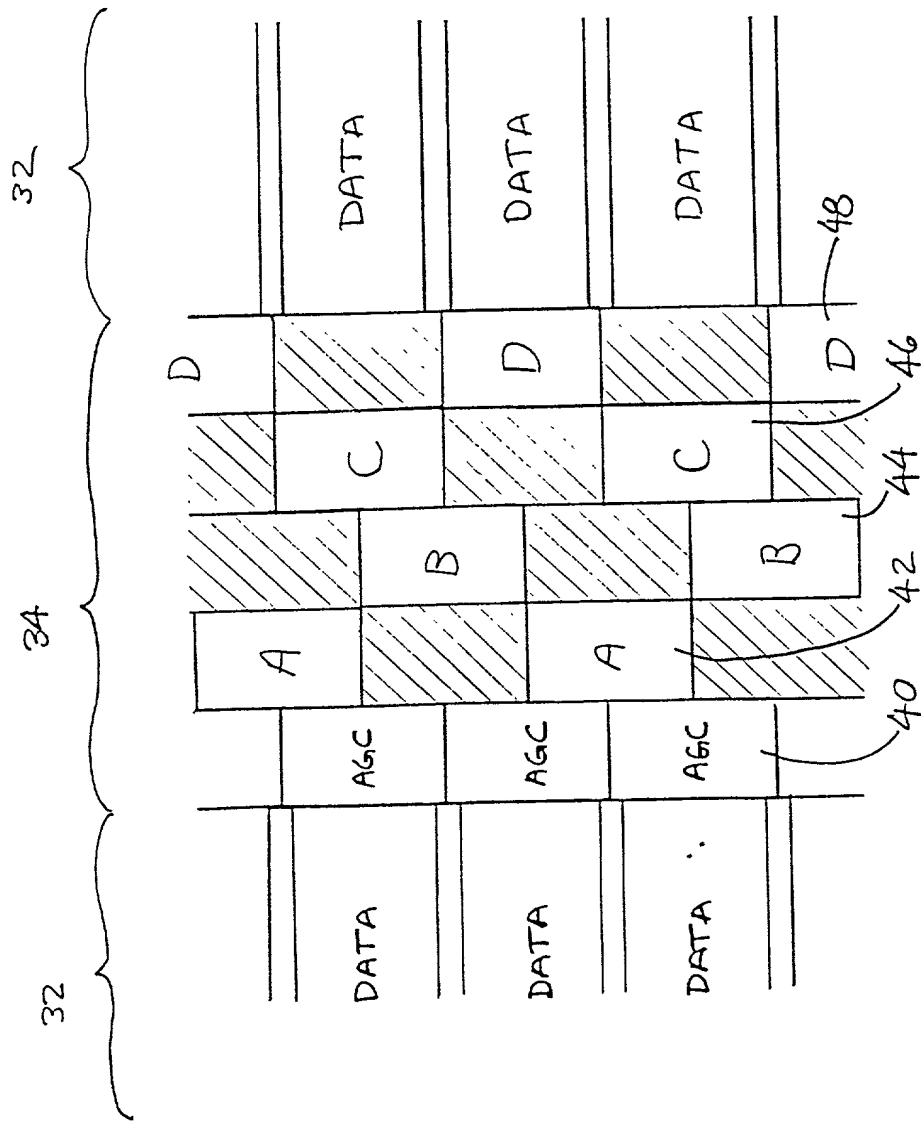


FIG. 3

AGC

Con D

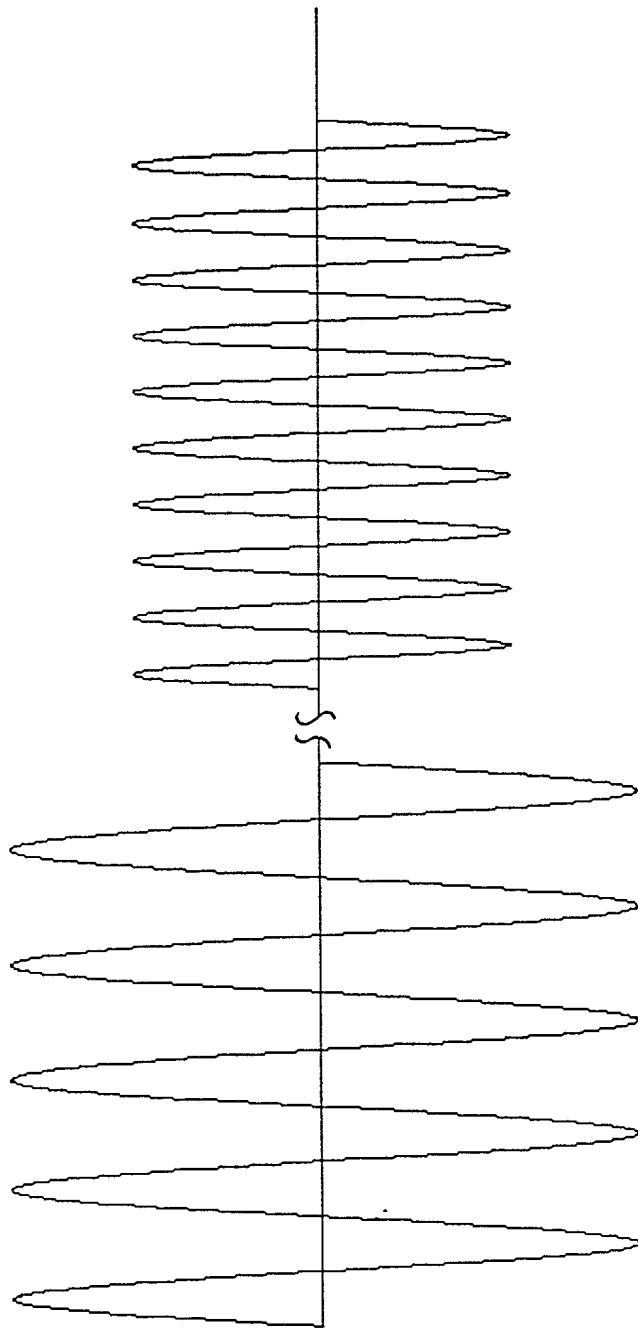


Fig. 4

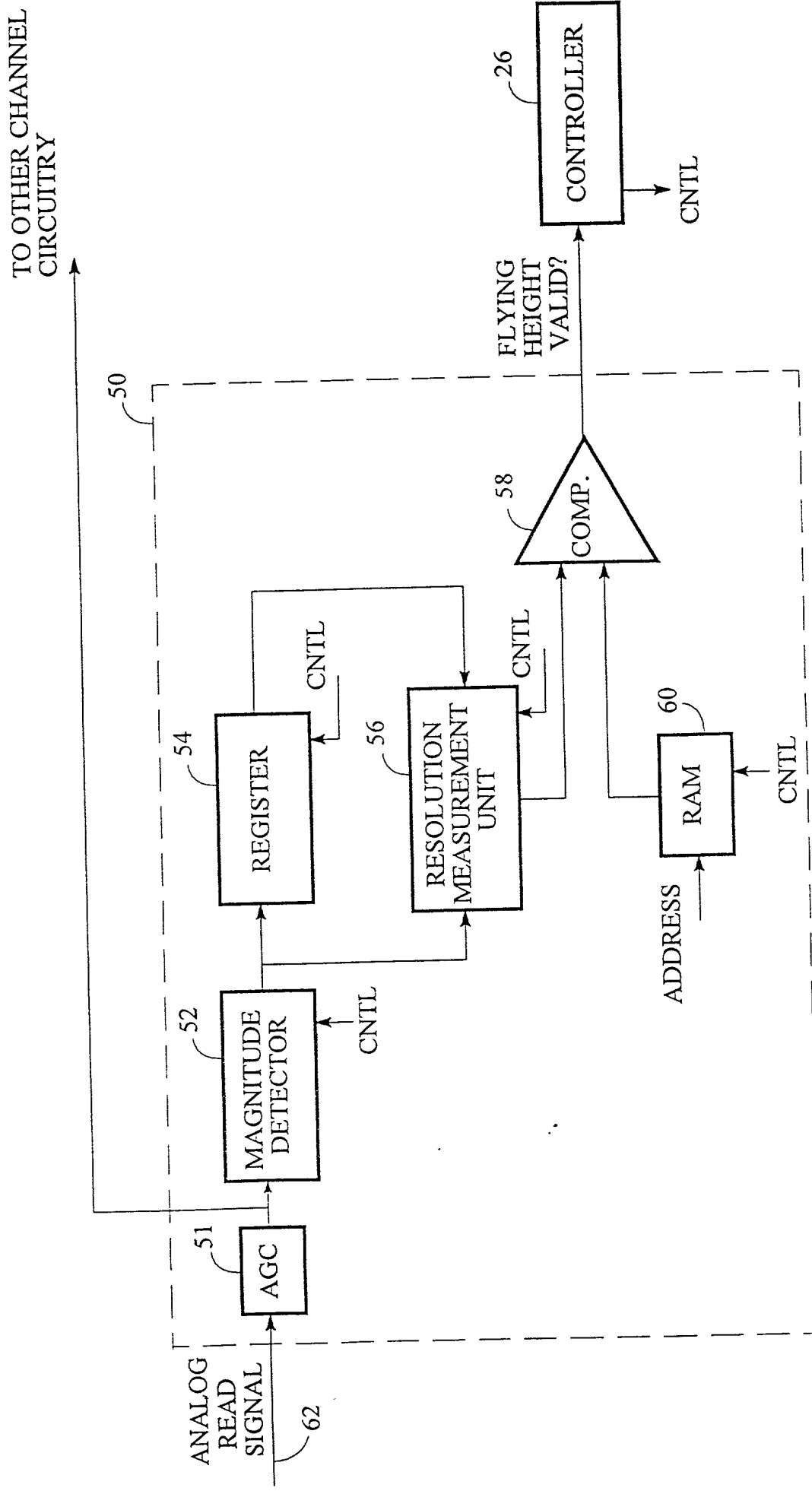


FIG. 5

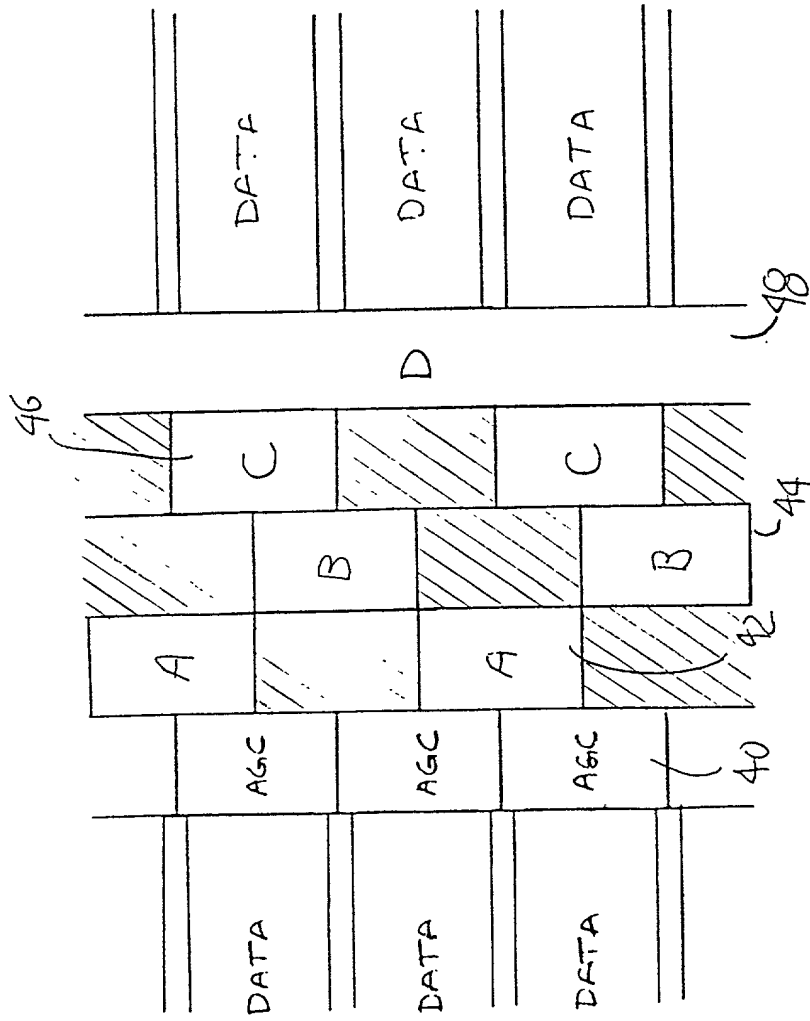


FIG. 6

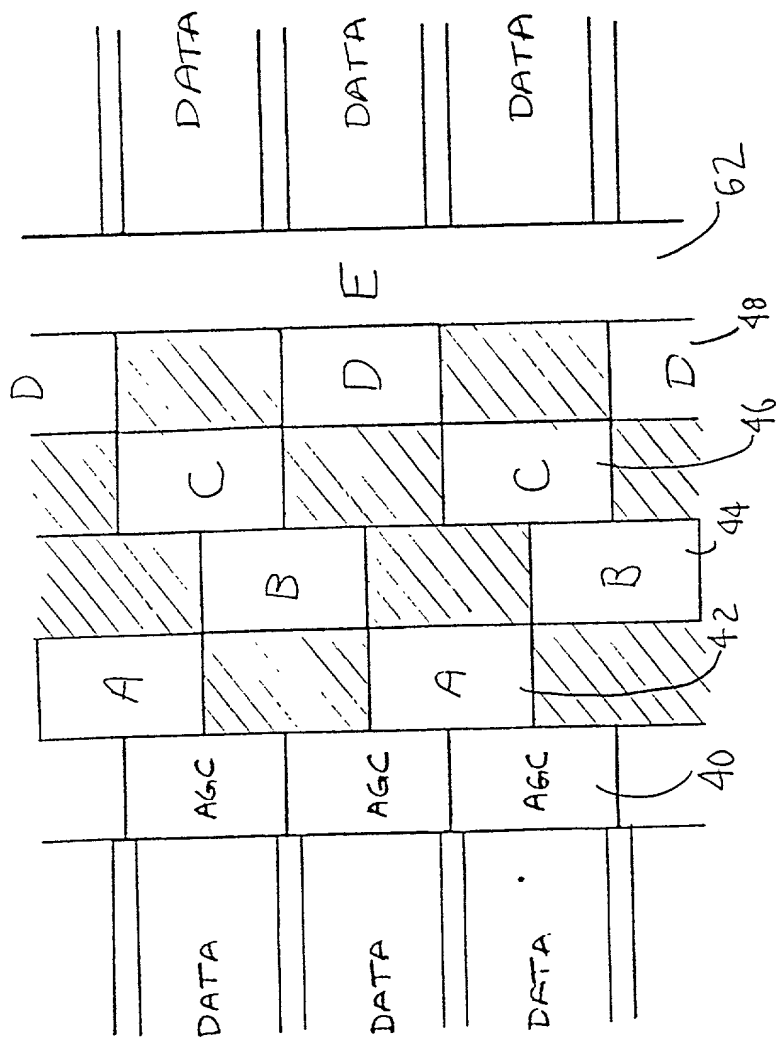
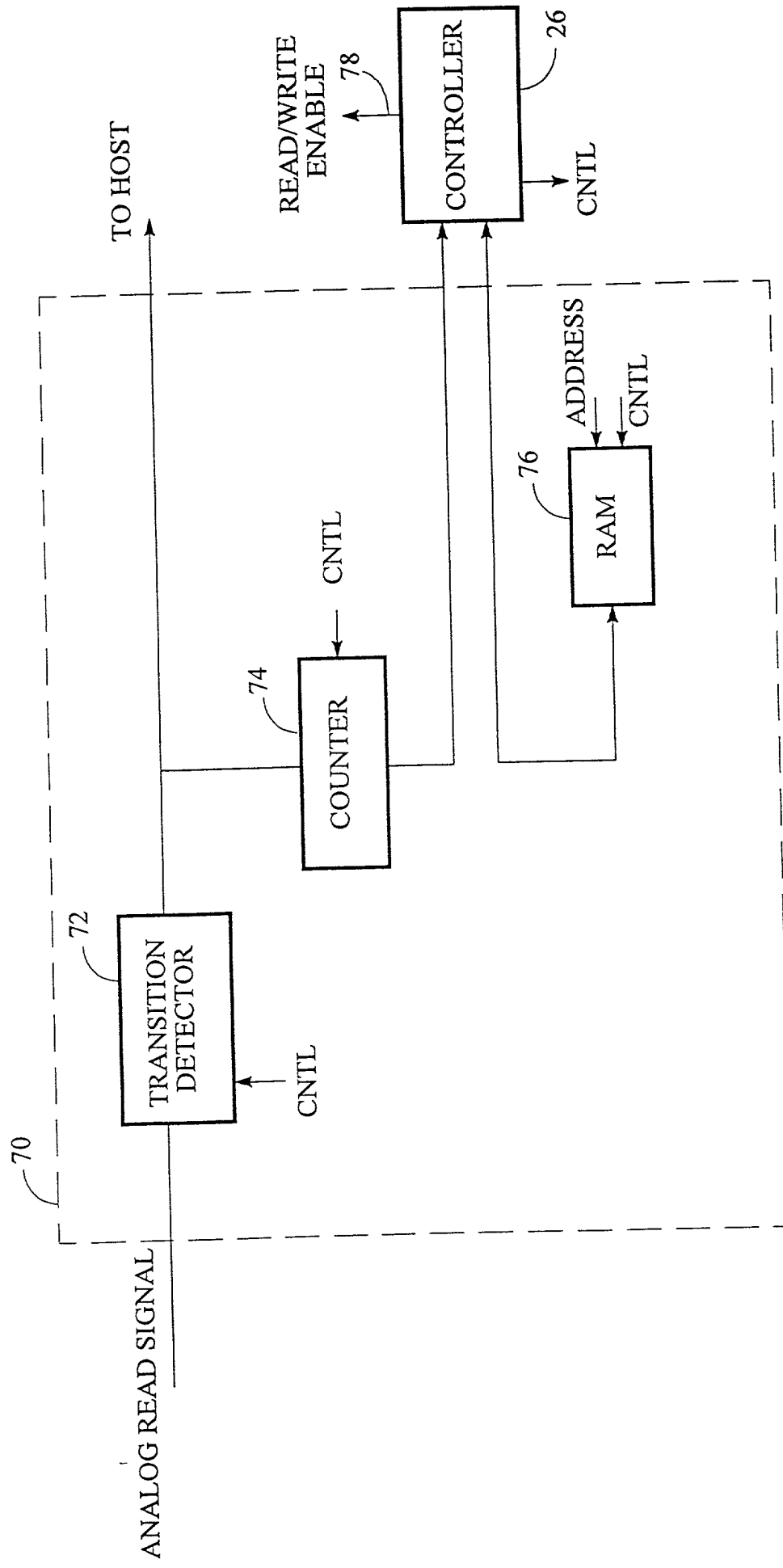


FIG. 7



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CHIRP

AGC

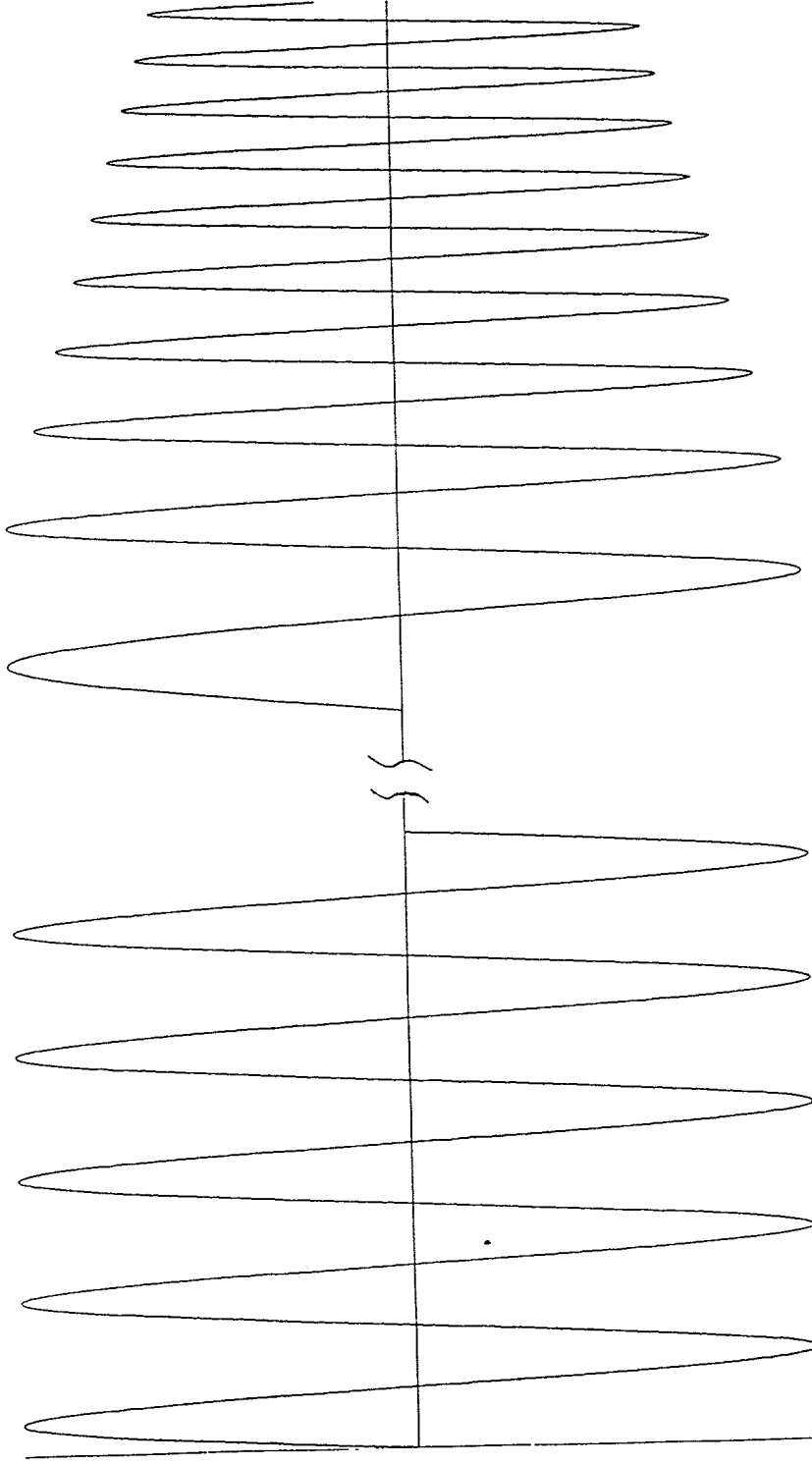


Fig. 9

RULE 63 (37 CFR § 1.63)
DECLARATION
FOR PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled "METHOD AND APPARATUS FOR DETECTING HEAD FLYING HEIGHT IN A DISK DRIVE", the specification of which is identified as Attorney File No. 3123-233 and attached hereto.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to patentability in accordance with 37 CFR 1.56(a) and (b) as set forth on the attached sheet indicated Page 3 hereof and which I have read.


I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)		<u>Day/Month/Year</u>	<u>Filed</u>	Priority Claimed	
<u>Number</u>	<u>Country</u>			<u>Yes</u>	<u>No</u>

I hereby claim the benefit under 35 U.S.C. 120/365 of all United States and PCT international applications listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in such prior applications in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information material to patentability in accordance with 37 CFR 1.56(a) and (b) which occurred between the filing date(s) of the prior application(s) and the national or PCT international filing date of this application:

<u>Application Serial No.</u>	<u>Filing Date</u>	<u>Status: patented, pending, abandoned</u>
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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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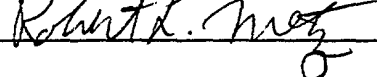
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37 CFR §1.56(a) and (b)
DUTY TO DISCLOSE INFORMATION MATERIAL
TO PATENTABILITY

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of a patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.*

*Note, 37 CFR §1.97(h) states: "The filing of an information disclosure statement shall not be construed to be an admission that the information cited in the statement is, or is considered to be, material to patentability as defined in §1.56(b)."